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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

EX PARTE

William F. Caton
Secretary, Federal Communications Commission
Mail Stop 1170
1919 M Street, N.W., Room 222
Washington, DC 20554

Dear Mr. Caton:

Re: CC Docket No. 96-45 -- Federal-State Board on Universal Service

Enclosed is a copy of a paper that we would like to have placed on the record in the above-referenced proceeding. Written by Frank Kelly and Richard Steinberg of Cambridge University, this paper proposes a model of competitive bidding to allocate universal service subsidies in high-cost areas. We believe that competitive bidding may provide an important means by which this universal service policy may be made more efficient. For this reason, we are offering this paper in an effort to promote discussion as to whether the Commission should employ such a model.

We have also forwarded copies of Professor Kelly and Steinberg's paper to the Office of Plans and Policy.

We are submitting two copies of this notice in accordance with Section 1.1206 (a)(1) of the Commission's Rules.

Sincerely,

Wayne Leighton
Senior Economist for Regulatory Affairs

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A Combinatorial Auction for COLR

Frank Kelly and Richard Steinberg
University of Cambridge

14 February 1997

Executive Summary

We describe a discrete-time auction procedure called PAUSE (Progressive Adaptive User Selection Environment) for use in assigning COLR responsibility. The PAUSE auction is based on and generalises the auction structure used for the PCS auctions; in particular, the auction proceeds by discrete rounds within stages driven by progressive activity rules. In addition, PAUSE incorporates synergies by allowing for every possible combinatorial bid; in particular, it incorporates the use of AUSM (Adaptive User Selection Mechanism) bidding, which has been tested in the laboratory at the California Institute of Technology.[1] By proceeding by discrete rounds in stages with progressive activity rules, the threshold problem and deception ('snake-in-the-grass') effect are lessened, and at the same time the computational effort required of the bidders is reduced. Finally, the auction can also accommodate multiple winners.

The inherent computational complexity of combinatorial bidding cannot be eliminated; however, our auction procedure is computationally simple for the auctioneer and thus is very efficient to run. The computational burden of evaluating synergies rests with the bidders claiming those synergies, while the auctioneer simply checks that a bid is valid. There is very little computational burden for small players interested in only a small number of assets. If *no* synergies are claimed, then the auction reduces to the auction of the type utilised for the PCS licenses.

[1] Bykowsky, M.M., R.J. Cull, and J.O. Ledyard, 'Mutually Destructive Bidding: The FCC Auction Design Problem', *Social Science Working Paper* 916, California Institute of Technology, 1995.

Overview of the Auction

Define a **PAUSE (Progressive Adaptive User Selection Environment) Auction** to be a two-stage auction with:

(i) In Stage 1, 'PCS-type' activity rules, i.e., three substages with progressive eligibility requirements and an improvement margin (bid increment) requirement;

(ii) In Stage 2, AUSM bidding in two substages with progressive eligibility requirements and and an *exact* improvement margin requirement;

(iii) No bid withdrawals and no bid waivers.

The PAUSE auction is designed to be fully general in that every possible combinatorial bid is available to the bidders. If, however, the auctioneer wishes to restrict the bids in any manner that he finds convenient to verify, the auction structure will accommodate this, and the auctioneer can announce to the bidders a list of attributes a bid must have. (An example of such an attribute might be: 'bids that are combinatorial are to be composed of geographically contiguous subsets of properties'.) This is formalised in the next section.

Definitions

Label *properties* $j \in J$, and *blocks* $k \in K$, where $K = K(J, A)$ is a set of subsets of J defined by a set of *attributes* A that are restricted to be computationally simple for the auctioneer to verify for each member of K.

A *partition* $P = (p_1, p_2, \ldots, p_r)$ is a collection $p_1, p_2, \ldots, p_r \in K$ such that $\bigcup_{i=1}^{r} p_i = J$, and $p_i \cap p_j = \varnothing$, $i \neq j$.

(In words, a partition is a grouping of all the properties in the auction into non-overlapping sets.)

A *composite bid* comprises a partition $P = (p_1, p_2, \ldots, p_r)$ together with an *evaluation*

$$(C(P); c(p_1), c(p_2) \ldots, c(p_r))$$

where

$$C(P) = \sum_{i=1}^{r} c(p_i),$$

(*)

and $c(p_i)$ is the *bid* for block p_i.

To be more precise, $c(p_i)$ is *the value of the bid for block* p_i. A composite bid consists of $3r+1$ pieces of information, capable of registration in a database. The first piece of information is the total value of the composite bid, $C(P)$. The $3r$ pieces of information are, for each i (i = 1, 2, ..., r): (1) the specification of the block p_i, (2) the value of the bid on the block, $c(p_i)$, and (3) the identity of the bidder for block p_i.

Items (1) and (2) are available from the database to all bidders; item (3) may be available only to the auctioneer and the bidder concerned, or may be public information.

The Procedure

Stage 1 - Bidding on Individual Properties

The Bidders: Each bidder submits a collection of bids on individual properties.

The Auctioneer: In each round, for each property the auctioneer checks that a bid on that property is *valid* by verifying that it decreases the value of the last accepted bid on that property by *at least* the specified bid increment. In each round, the lowest valid bid on each property is accepted. The round ends when bidding ceases on all properties. Stage 1 is divided into three substages that correspond to the stages of the PCS auctions. At the conclusion of the third substage, the leading (i.e., lowest) bids on the properties are registered to their respective owners.

Activity Rules: A bidder is *active* on a property if he has the leading bid from the previous round or submits an acceptable bid in the current round. Each of the three substages contains an unspecified number of bidding rounds. The bidders must remain active on properties covering, respectively in the three stages, 60 per cent, 70 per cent, and 80 per cent of the number of subscribers for which they wish to remain eligible to bid. (In this document, by *subscribers* we mean 'subscribers counted under the universal service provisions for support for high cost areas'.) The transition from substage 1 to 2 occurs when there are bids on no more than 10 per cent of the subscribers for three consecutive rounds, from substage 2 to substage 3 when there are bids on no more than 5 per cent of the subscribers for three consecutive rounds.

Stage 2 - Combinatorial Bidding

The Bidders: Each bidder submits a single composite bid on a collection of properties, where each bidder's partition $P=(p_1,p_2,\ldots,p_r)$ is restricted to $p_i \in K$, where $c(p_i)$ is either a new bid for block i, or a registered bid. Stage 2 is broken down into two substages.

The Auctioneer: In each round, the auctioneer checks that a composite bid is *valid* by verifying that:

(i) each bid claiming to be registered is indeed registered in the database, and that new bids satisfy $p_i \in K$,

(ii) equation (*) holds, i.e., the value $C(P)$ of the composite bid is indeed the sum of the bids on each of its blocks, and

(iii) $C(P)$ is less than the value of the last accepted composite bid by *exactly* the specified bid increment.

In each round of Stage 2, the new bids on the blocks $\{c(p_i)\}$ are registered to their respective owners, and the lowest valid composite bid is accepted. The round ends when bidding ceases.

Activity Rules: Each of the two substages contains an unspecified number of bidding rounds, with bidders required to be active on 90 per cent of the subscribers in the first substage, and on 95 per cent of the subscribers in the second substage. The transition between stages occurs when there are bids on no more than 10 per cent of the subscribers for three consecutive rounds. A bidder is *active* on a property if his bid on a block containing that property forms part of the accepted composite bid of the previous round, or if he submits a valid bid in the current round on a block containing that property.

Other Auction Rules

Bid Withdrawals. No bid withdrawals are allowed.

In the PCS auctions, bid withdrawals were permitted. Specifically, a high bidder withdrawing its bid during the course of the auction was required to pay the difference between its bid and the price for which the licence ultimately sold; a winning bidder withdrawing after the close of the auction would suffer an extra penalty. It may be asked why bid withdrawals were permitted, since they complicate the auction. Paul Milgrom, in his attachment to GTE's Comments in Response to Questions (CC Docket No. 96-45) clearly states the motivation: 'In effect, a bid withdrawal substitutes partially and quite imperfectly for combinatorial bidding.'

Bid Waivers. For simplicity, there are no bid waivers.

Bid Increments. In each round there is an *improvement margin requirement*:

If $c(p_1), c(p_2), \dots, c(p_s)$ are the *new* bids in a composite bid, then the evaluation must improve on the previous best evaluation by *exactly* εs, i.e., an improvement of ε per block on average. (Alternatively we might use $|p_i|$, the number of properties in p_i, or $||p_i||$, the total number of subscribers in all the properties in p_i.) Here ε can be used by the auctioneer to control the speed of the auction.

McAfee and McMillan (1996)[2] report that in the MTA auction, aggressive bidding in early rounds took the form of 'jump bidding': entering bids far above the required minimum. In a combinatorial auction, jump bidding for a block of several properties would be effective at preventing small players from piecing together a comparable composite bid (the threshold effect). Our rule that the improvement margin has to be an exact increment is designed to lessen the threshold effect. It also helps keep the computation requirement down, by limiting the ranges of possibilities that need to be considered by bidders.

Multiple Winners. Multiple winners may be accommodated by the following amendment. All that is needed is an upper bound k on the number of multiple winners. (By default, k can be taken to be the total number of bidders in the auction.) Each property j is then replaced by k properties $j_1, j_2, j_3, \dots, j_k$. Now require for the validity of a composite bid that, for each j, the bid does not allocate properties j_s and j_t $(s \neq t)$ to the same player. Note that it is now essential that the bidder identities be made public.

Multiple winners are selected to be any bids within an auctioneer-defined *tolerance* (e.g., 15 per cent) of the lowest bid.

[2] McAfee, R.P. and J. McMillan, 'Analyzing the Airwaves Auction', *Journal of Economic Perspectives* 10, 1, 1996, 159-175.

Technical Appendix: Computational Complexity

(i) Since in each round the value of the accepted composite bid must decrease by at least ε over the previously accepted composite bid, the number of rounds in total is bounded above by $C_0(P_0)/\varepsilon$, where $C_0(P_0)$ is the value of the opening composite bid (perhaps set by the auctioneer).

(ii) Let B be the number of bidders. Since each bidder is allowed to make at most one composite bid per round, the maximum number of bids that needs to be registered by the auctioneer is bounded above by

$$\frac{C_0(P_0)}{\varepsilon} B|J|.$$

In general, it may be an NP-complete problem for a bidder to determine whether he can make a composite bid that beats the currently accepted composite bid. The results of Rothkopf *et al.* (1996)[3] show that, if the form of composite bids is restricted in one or other of several possible ways, then the problem becomes manageable. However, bidders are unlikely to agree upon the form of the appropriate restriction on composite bids. We view the elicitation of the form and size of potential synergies as a major purpose of the auction.

Work on computationally difficult problems shows that in several situations where finding the exact optimum is hard, finding a good approximation to the optimum with high probability may be relatively easy (Jerrum and Sinclair 1996)[4]. It is our belief that the traditional problems of elicitation and gaming are more serious difficulties than the possible computational burden on those bidders claiming complex synergies.

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[3] Rothkopf, M.H., A. Pekec, and R.M. Harstad, 'Computationally Manageable Combinational Auctions', Rutgers University, May 1996.

[4] Jerrum, M. and A. Sinclair, 'The Markov Chain Monte Carlo Method: An Approach to approximate Counting and Integration', in Dorit S. Hochbaum (ed.), *Approximation Algorithms for NP-Hard Problems*, PWS Publishing Company, Boston, Massachusetts, 1996.